AERONET Precipitable Water Vapor Validated for Global Applications

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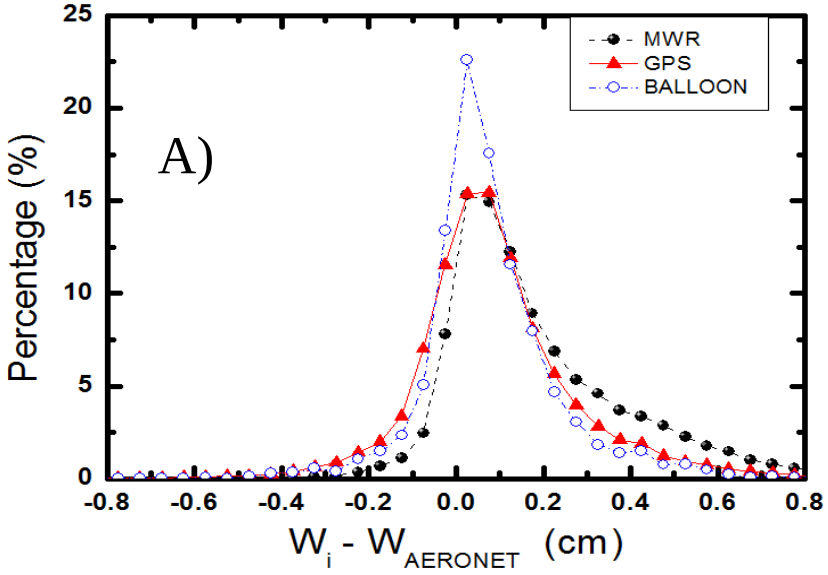
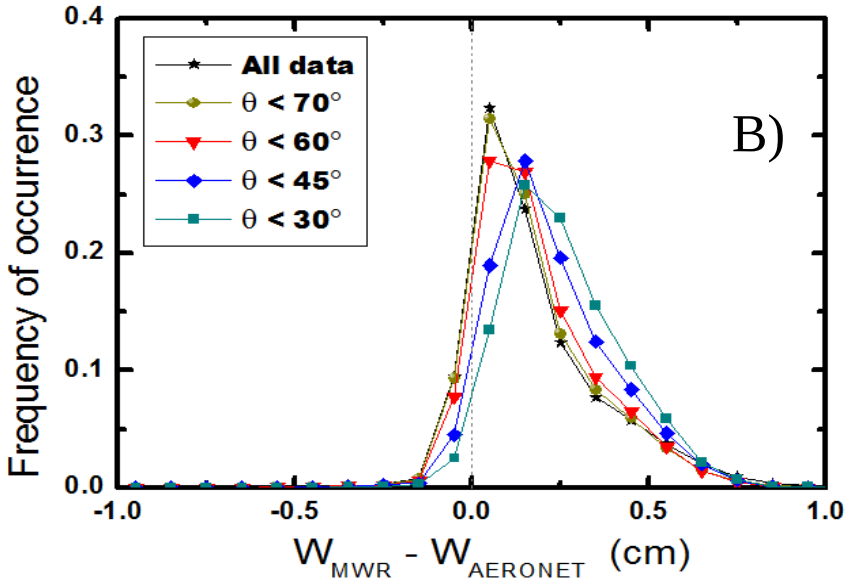
Histograms of the Inter-comparisons for the Whole Database



Inter-comparisons with Varying Solar Zenith Angle (Θ)



AERONET is that sun photometers are located in many remote areas where other water vapor instruments do not exist. (A) The evaluation of AERONET precipitable water vapor ($W_{AERONET}$) versus a large set of microwave radiometer (W_{MWR}) and GPS (W_{GPS}) data reveals a mean low bias in $W_{AERONET}$ of ~9.0% and ~6.0%, respectively. Comparison with the radiosonde measured W also reveals that $W_{AERONET}$ has a mean low bias of ~ 5.0%. (B) Also, W_{MWR} displays a dependency with solar zenith angle (Θ). Differences are larger for low values of Θ which are mainly around noon.

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References:

Daniel Perez-Ramirez, David N. Whiteman, Alexander Smirnov, Hassan Lyamani, Brent N. Holben, Rachel Pinker, Marcos Andrade and Lucas Alados-Arboledas, 2014: Evaluation of AERONET precipitable water vapor versus microwave radiometry, GPS and radiosondes at ARM sites, *Journal of Geophysical Research – Atmospheres*, 119, 9596 – 9613.doi: 10.1002/2014JD021730

Data Sources: For the inter-comparisons of precipitable water vapor, we used the values provided by the NASA Aerosol Robotic Network (AERONET) at the ARM sites at the Southern Great Plains (Oklahoma), Tropical Western Pacific (Nauru) and Barrow (Alaska). At these locations, there were co-located ARM microwave radiometry and Vaisala radiosondes launches. Also, GPS data from the SOUMINET network were used. For the applicability of AERONET precipitable water vapor to remote areas we used AERONET data at the remote areas of Granada (Spain), Ilorin (Nigeria), Midway (USA), Cordoba (Argentina) and La Paz (Bolivia).

AERONET data: http://aeronet.gsfc.nasa.gov/
ARM microwave radiometers and radiosonde data: http://www.archive.arm.gov/
GPS data from SOUMINET: http://www.suominet.ucar.edu/

Technical Description of Figures:

Figure A: Using the database generated by combining the measurements at the three ARM sites which cover a wide range of precipitable water vapor, we generated percentage histograms for the inter-comparisons. The histograms approximate a normal distribution, with mean values representative of the differences between the different techniques. Thus, the histograms reveal that AERONET values of precipitable water vapor are lower than those of the microwave radiometry and GPS by approximately 6.0 – 9.0 % . For the inter-comparisons with radiosondes, AERONET values are approximately 5 % lower.
Figure B: The inter-comparisons were also performed as a function of solar zenith angle (Θ). The plot reveals that the differences are larger for low values of Θ which are mainly around noon. For GPS and radiosondes we performed similar analysis (graphs not shown) and no dependence with Θ was observed. Therefore, we speculate that dependences with Θ are associated with microwave radiometers which is an effect that is currently under study.

Scientific significance, societal relevance, and relationships to future missions: Water vapor is a key element in the Earth's climate system because of its important role in the hydrological cycle, its condensation into liquid provides latent heating and it is the most important gaseous element of infrared opacity in the atmosphere. Therefore, accurate water vapor measurements are needed in meteorological and climatological studies, including weather forecast and energy budget studies. Here, the capabilities of the AERONET network that rely on sun-photometry measurements have been validated against more advanced techniques. The great advantage of AERONET is that sun photometers are located in many remote areas where other water vapor instruments do not exist. The results of this study demonstrate that AERONET precipitable water vapor retrievals can be used to help validate satellite measurements and global models. Also, the results presented here are a starting point for the use of the Marine Aerosol Network (a sub-network of AERONET) that makes measurements on cruises which will provide a unique aerosol database over the oceans.

Tropical Upper-Troposphere Ice Clouds Are Systematically Tilted Poleward

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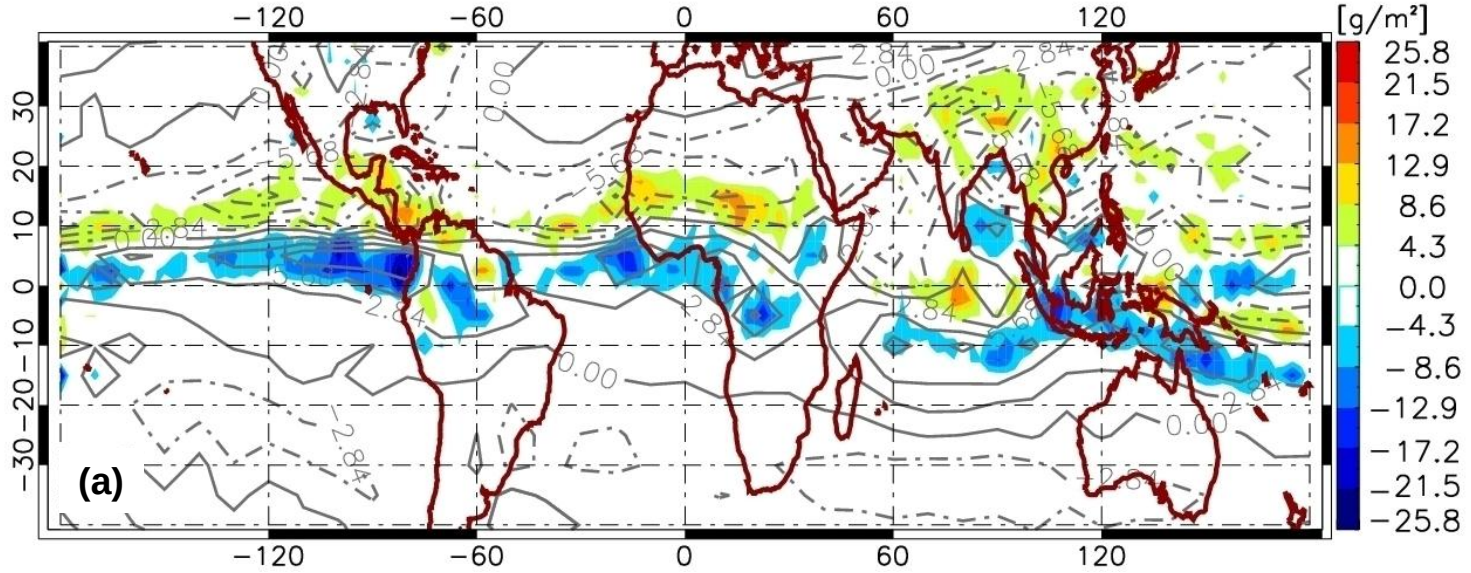
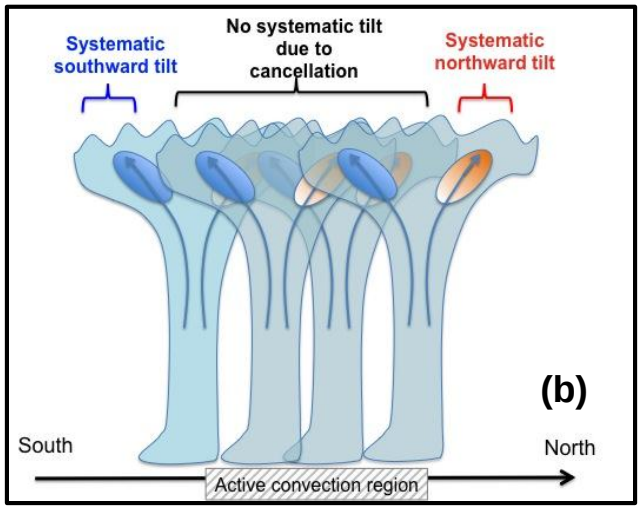
CloudSat IWP Diff (South-North, shades); MLS TB Diff (Day-Night, contours)





Upper-Tropospheric ice clouds (anvils and cirrus ouflows extending from deep convection) have small-scale (~1 km horizontal) structures that are organized and systematically tilting poleward in the tropics, as revealed by CloudSat ice water path (IWP) and Aura MLS Radiance (TB). These tilted cloud structures cover regions over hundred kilometers, contributing up to 20% of IWP uncertainty if not accounted for in remote sensing from space.

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Gong, J., D. L. Wu, and V. Limpasuvan. 2014. "Meridionally-tilted ice cloud structures in the tropical Upper Troposphere as seen by CloudSat." *Atmospheric Chemistry and Physics Discussions*, **14**: 24915-24942 [10.5194/acpd-14-24915-2014], in press for *Atmospheric Chemistry and Physics*.

Gong, J., and D. L. Wu. 2013. "View-angle-dependent AIRS cloudiness and radiance variance: Analysis and interpretation." *Journal of Geophysical Research- Atmospheres*, **118 (5):** 2327-2339 [10.1002/jgrd.50120]

Data Sources: CloudSat 2B-CWC-RO V008 ice water content (IWC) product supported by CloudSat Team. Joint IWC retrieval product of CloudSat CALIPSO-MODIS (DARDAR) supported by ICARE Thematic Center. Level 1 Aura MLS radiance product supported by MLS team; MERRA daily wind product supported by NASA GMAO. We are grateful for support from NASA NNH10ZDA001N-ESDRERR (Earth System Data Records Uncertainty Analysis) project. V. L. was supported by the National Science Foundation (NSF) under grants AGS-1116123 and AGS-15 MRI-0958616 and the Coastal Carolina University Kerns Palmetto Professorship endowment.

Technical Description of Figures:

Figure a: CloudSat ΔIWP (colored shades; southward-looking view minus northward-looking view; 11-17 km IWC integration, cloud registration determined by location at 14 km) and Aura MLS 640 GHz ΔTB (descending minus ascending orbits to mimic CloudSat viewing geometry, contours, with dashed indicating negative, and solid positive values) averaged over June-July-August, 2007-2010. The maps are interpolated to 2° × 2° grid box, and the correlation coefficient between CloudSat ΔIWP and MLS ΔTB is -0.68. For CloudSat, IWC is first interpolated to 0.25 km vertical grid, and IWP integration is performed by staggering every grid each time, which is equivalent to a view angle of 77°. Positive (negative) values indicate that the cloud is systematically tilted northward (southward). MLS 640 GHz mainly observes the upper-tropospheric ice cloud signals, and has a shallower viewing angle (86°). MLS ΔTB has a cloud diurnal cycle embedded in the signal.

Figure b: Schematic diagram showing the interpretation of systematic poleward UT cloud tilts at the north and south peripheries of active tropical convection regions. For each single convective cloud, anvils and cirrus associated with the convective core tend to fan outward. Within the active deep convective center, the effect cancels out when numerous clouds are added together; however, the adding effect becomes positive near the peripheries of the deep convective region, resulting in systematic tilt signals there. The width of the systematic tilt of the cloud band extends several degrees of latitude, and the ΔIWP could be as large as 20% of the mean IWP.

Scientific significance, societal relevance, and relationships to future missions: This study for the first time presents a global characterization of cloud tilt structures in the upper troposphere within the meridional direction. The observed IWP differences in the paired slant-views have important implications for remote sensing and modeling of global cloud systems, including satellite retrieval of cloud properties, atmospheric momentum and energy budget, evaluation of cloud radiative effect, and modulation of the hydrological cycle. The study raises questions about the wind-tilt angle relationship, and about potential impacts on energy, momentum and hydrological cycles. More importantly, as GCMs continue to improve their resolution, vertically tilted cloud structures will become explicitly resolved. The modeled cloud three-dimensional inhomogeneity will need to be subjected to verification or close scrutiny against ice cloud observations from future satellite missions that will hopefully be even more detailed and accurate than those used in this study.

First demonstration of formaldehyde (HCHO) retrieval with Suomi NPP OMPS

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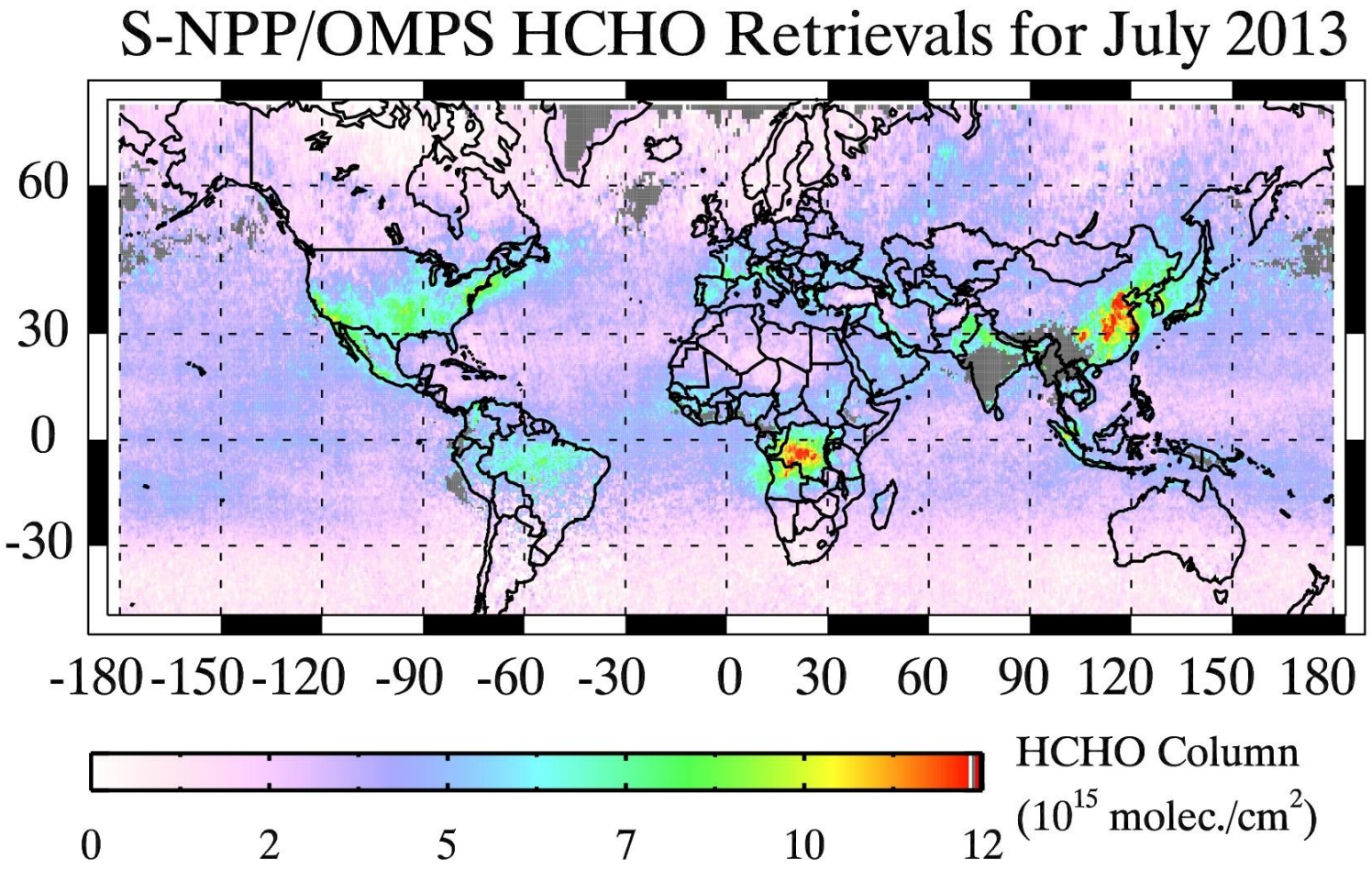

- HCHO retrievals provide insights into the sources of volatile organic compounds (VOCs) that contribute to smog and haze.
- While HCHO was not an anticipated OMPS product, a new principal component analysis technique produces retrievals of comparable quality to those from other sensors which allows for the continuation of a long-term record started by the Aura Ozone Monitoring Instrument (OMI).

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References:
Li, C., J. Joiner, N. A. Krotkov, and L. Dunlap (2015), A new method for global retrievals of HCHO total columns from the Suomi National Polar-orbiting Partnership Ozone Mapping and Profiler Suite, *Geophysical Research Letters*, **42**, doi:10.1002/2015GL063204.
Li, C., J. Joiner, N. A. Krotkov, and P. K. Bhartia (2013), A fast and sensitive new satellite SO_2 retrieval algorithm based on principal component analysis: Application to the Ozone Monitoring Instrument, *Geophysical Research Letters*, **40**, doi:10.1002/2013GL058134.

Data Sources: Suomi National Polar-orbiting Partnership (S-NPP) Ozone Mapping and Profiler Suite (OMPS) HCHO retrievals conducted in this research used input from OMPS L1B radiance data and L2 O_3 and cloud research data, downloaded from the website of the NASA OMPS science team (http://ozoneaq.gsfc.nasa.gov/). Global Fire Emissions Database (GFED) burnt area data product were downloaded from http://www.globalfiredata.org.

Technical Description of Figures:
Map: Global monthly mean HCHO vertical column density for July 2013 retrieved with the S-NPP OMPS instrument using a new algorithm based on principal component analysis (PCA) of measured radiances. The algorithm extracts spectral features (principal components, or PCs) from OMPS radiance data in the spectral range of 328.5-356.0 nm, and fits the leading PCs (that explains over 99.9999% of the spectral variance) and pre-computed HCHO Jacobians to estimate HCHO loading while minimizing interferences. HCHO Jacobians represent the sensitivity of OMPS radiances to a perturbation in HCHO column amount. They are computed from input OMPS cloud and ozone data, viewing geometry, surface reflectivity, and a *priori* climatological HCHO profiles from the Global Modeling Initiative (GMI) simulations. Data have been gridded into 0.5° × 0.5° resolution, after excluding pixels near the edge of the swath or having cloud radiance fraction > 0.3. Gray-shaded grid cells have less than 10 samples during the month. Overall the retrievals of HCHO from the Suomi S-NPP/OMPS instrument for July 2013 capture its various sources worldwide, including biogenic and anthropogenic emissions as well as biomass burning. For regions where the dominant HCHO source is biomass burning (*e.g.*, Australia), there is good correspondence between OMPS-retrieved HCHO and fires.

Scientific significance, societal relevance, and relationships to future missions: Satellite HCHO retrievals have been useful in providing constraints on the emissions of non-methane volatile organic compounds (NMVOCs) that are important precursors of tropospheric ozone and organic aerosols that can adversely affect air quality. But satellite retrievals suffer from relatively large uncertainty due to weak signals and strong interferences. There is also significant difference between different satellite instruments or algorithms. The PCA algorithm developed in this study can be potentially applied to different polar orbiting satellite instruments such as OMI, OMPS, GOME, GOME-2, and TROPOMI, as well as geostationary instruments such as TEMPO and GEMS, and help to build long-term, consistent HCHO datasets that can provide insights into the climate effects on atmospheric chemistry and air quality.